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STATUS REPORT

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"A Correlative Investigation of the Propagation of ULF Wave Power Through the Dayside Magnetosphere"

January 1, 1992 – June 30, 1992

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I. Overview

NASA grant NAGW-1567 was awarded to Augsburg College to support Mark Engebretson, Kenneth Erickson, and a student in a multisatellite study of the propagation of ULF wave power through the dayside magnetosphere. Project funding began in January 1989, and was extended through December 1992.

During the period covered by this report, January 1, 1992 through June 30, 1992, we completed work on one paper, continued work on two additional studies, and began work on another. Some results of the first two of these studies were presented at an invited review on dayside ULF pulsations at the 1992 GEM meeting in Snowmass, Colorado June 28-30, 1992.

II. Scientific Accomplishments

A. Radial Pulsation Study

A multisatellite study of radial pulsations, "The spatial extent of radial magnetic pulsation events observed in the dayside near synchronous orbit," by Mark Engebretson, David Murr (STUDENT), and Kenneth Erickson of Augsburg, Robert Strangeway of UCLA, David Klumpar and Stephen Fuselier of Lockheed Palo Alto Research Laboratory, and Larry Zanetti and Tom Potemra of JHU/APL, submitted to the Journal of Geophysical Research October 10, 1991, was revised and resubmitted April 13, 1992 and accepted for publication April 15. Typesetting of this paper was completed at Augsburg in early July, 1992.

In this paper on dayside radially polarized Pc 4 pulsations, we proposed a new model for wave onset. Although we agree that bounce resonant wave-particle interactions involving particles of ring current energies probably supply the free energy for the observed waves, we have found strong evidence that the influx of cold / thermal plasma as a result of plasmaspheric refilling/expansion during quiet times triggers the instability of these more energetic particles.

During the paper's revision we added a time-of-flight calculation of standing wave periods to estimate near-equatorial particle densities, and found them to be in good agreement with the limited density estimation data available on board AMPTE CCE from the Plasma Wave Experiment (PWE) instrument [Scarf et al., 1985].

B. Wave Polarization Study

One of the goals of this project was to study the propagation of mid-period ULF wave energy through the dayside magnetosphere. Recent case studies and statistical surveys have provided a large body of evidence that upstream waves related to a quasi-parallel bow shock geometry are a primary source of dayside Pc 3-4 pulsations. These waves are most prominent in the azimuthal component, where multiple harmonic resonances are often observed, but more diffuse power is also often enhanced in compressional and radial components. Color Fourier spectrograms of magnetometer data from the AMPTE CCE satellite were produced routinely during the entire satellite lifetime of over 4 years. A feature which was noted early in the satellite lifetime was that although the azimuthally polarized harmonic pulsations appeared to have roughly uniform amplitude in many cases, the compressionally polarized pulsations, which exhibit power in a characteristically more broadband distribution in this same frequency range, had their largest amplitude near local noon and at the largest L values.

In this study, presented initially at the Fall 1991 AGU meeting [Engebretson et al., 1991b] we compared the integrated amplitude of Pc 3-4 wave power in these components as a function of L shell and magnetic local time, using data obtained by the equatorially orbiting AMPTE CCE satellite (in a highly elliptical orbit with apogee at 8.8 RE) during Fall 1984. We have found that statistically, as well as in example events, compressional and radial power fall off away from local noon and from the subsolar point, while azimuthal power has a much more uniform distribution in local time and distance from the subsolar point.

It has been the conventional wisdom that azimuthal harmonic pulsations are driven by mode conversion of compressional (fast mode) ULF waves into transverse (Alfven mode) ULF waves. The AMPTE CCE spectrograms gave us the first evidence that other mechanisms might need to be invoked to explain the detailed characteristics of the observed harmonic pulsations.

STATISTICAL RESULTS

We show in Table 1 a statistical summary of the two data sets (harmonic and more broadband) used in the first portion of this study. We show the total number of intervals, the maximum and minimum, the logarithmic mean, and the values of the logarithmic mean +/- one sigma (determined by multiplying or dividing the logarithmic mean by the logarithmic standard deviation) for the power in each component (BR=radial, BE=eastward, or azimuthal, and BN=northward, or compressional) and for the power ratios BR/BN and BE/BN.

TABLE 1: POWER IN THE 20 - 50 mHz FREQUENCY RANGE

1. HARMONIC PULSATION EVENTS				N = 459	
	BE/BN	BE	BN	BR/BN	BR
MAX.	43.683	22.999	8.047	23.754	13.419
lmn*lstdv	5.701	5.688	1.960	1.923	1.992
logMEAN	2.698	1.782	0.661	0.986	0.652
logSTDDEV	2.113	3.192	2.965	1.950	3.055
lmn/lstdv	1.277	0.558	0.223	0.513	0.213
MIN.	0.342	0.046	0.035	0.178	0.034

2. MORE BROADBAND PULSATION EVENTS				N = 419	
	BE/BN	BE	BN	BR/BN	BR
MAX.	16.491	55.079	10.897	9.055	33.539
lmn*lstdv	3.389	5.321	2.978	1.863	3.019
logMEAN	1.641	1.390	0.847	0.938	0.796
logSTDDEV	2.065	3.828	3.516	1.986	3.793
lmn/lstdv	0.795	0.363	0.241	0.472	0.210
MIN.	0.194	0.026	0.035	0.149	0.024

Scatter diagrams of harmonic and more broadband event occurrences as a function of local time and L shell were then prepared according to various criteria in order to look for spatial patterns. We show a selection of these scatter diagrams in Figures 1 and 2.

The first panel in Figure 1 shows the location of all 459 harmonic events. The next five panels show those events with power levels larger than one standard deviation above the logarithmic mean for the BN, BR, and BE power, and the BE/BN and BR/BN ratio; the final two panels show those events with power levels lower than one standard deviation below the logarithmic mean for the BE/BN and BR/BN ratio.

In Figure 2a we show the location of all 419 more broadband events. The next two panels show those events with values of the BN power level and the BE/BN power ratio higher than one standard deviation above the logarithmic mean.

In both data sets there is a clear separation of occurrence location between events with largest BN value and those with largest BE/BN and BR/BN values. Although the locations are not mutually exclusive, the largest BN values occur near the subsolar point (large L values, near local noon), while the largest BE/BN and BR/BN values occur away from these locations. This separation is strongest for the resonant pulsation category, but is also evident for the more broadband pulsations. The largest BE values appear to be rather evenly distributed, consistent with the findings of Anderson et al. [1990] based on the complete 1984 data set but using a different methodology. The distribution the largest BR values appears to be intermediate between those of the BN and BE values.

A comparison of those distributions with the largest BR/BN and BE/BN ratios (panels e and f of Figure 1) to those with the smallest BR/BN and BE/BN ratios (panels g and h of Figure 1) also shows a clear spatial separation, with larger ratios predominantly inward of the smaller ratios. As was the case for the BN and BE/BN comparison, the trends were similar but not as clear for the more broadband population.

A final step in our study, not yet performed, will be to calculate average power levels and deviations for each category in local time – L shell bins.

IMPLICATIONS

Theoretical studies of the transport of solar wind generated wave energy into the magnetosphere have until recently focused on direct entry of compressional wave energy across the magnetopause, usually near the equator, followed by mode conversion to generate resonant transverse pulsations. Verzariu [1973] and Wolfe and Kaufmann [1975] showed theoretically that compressional wave power could enter, but with severe attenuation, directly

across tangential discontinuities at the equatorial, subsolar magnetopause. Refraction effects were expected to spread the wave energy somewhat, and the waves were expected to attenuate gradually as they passed into the magnetosphere, coupling some of their energy into transverse modes. One-fluid MHD calculations nearly a decade later by Kwok and Lee [1984] suggested that ULF waves of all polarizations could propagate much more efficiently across rotational discontinuities, in association with the reconnection process. Compressional waves are launched in all directions into the magnetosphere, and transverse waves are guided along cusp and low latitude boundary layer (LLBL) field lines toward low altitudes. Compressional waves were assumed to couple and attenuate as they traveled inward, as in the earlier models.

The observation that compressional wave power is strongest at the highest L shells and near local noon for both the harmonic and more broadband categories supports the idea that a considerable amount of compressional wave power enters the dayside magnetosphere near the subsolar point.

The observation that the average BE/BN ratio is larger for harmonic pulsation events than for the more broadband pulsation events is consistent with resonant excitation of the harmonics, as a repeated driving of a resonant system should increase the amplitude of its resonant oscillation. The average BR/BN ratio is lower, but roughly the same for harmonic and broadband events, consistent with the lack of observed resonant behavior in the BR component in the Pc 3-4 frequency range.

The observations, however, that azimuthal harmonic wave power (and to a lesser extent broadband wave power) has a roughly uniform power distribution on the dayside, and that the ratio of both azimuthal and radial power to compressional wave power is in fact stronger away from the subsolar point,

suggest that the coupling between compressional and transverse pulsations is surprisingly weak, and that some other process is (also) involved in creating and sustaining the transverse pulsations.

DISCUSSION

As noted above, our studies of AMPTE CCE pulsations have found that the amplitudes of compressional and transverse wave power in the Pc 3-4 range exhibit different spatial variations. These results cast doubt on the idea that mode coupling from compressional wave power transmitted earthward from the subsolar, equatorial magnetopause is the driving source for these waves.

The statistical results of Anderson et al. [1990], based on all the AMPTE CCE data for its first 15 months of operation, also provide evidence regarding entry for Pc 3-4 wave power: while Pc 5 pulsations (their "fundamental events") displayed a prominent and consistent trend of increasing occurrence with increasing L, with occurrence frequency for L = 8 to 9 approximately double that for L = 6 to 7, the most intense harmonic resonance events (Pc 3-4) were observed with nearly uniform occurrence at all L values from L = 5 to 9. The observations cited above thus imply that while propagating compressional waves may well power Pc 5 pulsations, they do not couple significant power into dayside transverse Pc 3-4 pulsations in the outer magnetosphere. These observations also suggest that mode conversion from equatorially transmitted compressional waves is a surprisingly inefficient process in the outer magnetosphere.

As an alternative model, Engebretson et al. [1991a] proposed an "ionospheric transistor" entry model, involving involving particle and current modulations and cusp/cleft precipitation. Transverse Pc 3-4 pulsations in the outer magnetosphere can in this way be driven by high latitude perturbations in

a manner analogous to the bowing of a violin string, which occurs not near the center but near the end. A schematic diagram of this high latitude model is shown in Figure 3. According to this model no wave mode coupling is required. Rather, momentum or pressure fluctuations in a high-beta magnetosheath (associated with upstream waves) impinge on the magnetopause and cause 1) modulated precipitation of otherwise trapped electrons, and/or 2) the launching of quasi-periodic transient field-aligned currents (arrows) along cusp/cleft/LLBL field lines. The modulated precipitation of electrons and/or time-varying currents convey wave information to the near-cusp ionosphere. Either indirectly (via modulated Pedersen conductivity) or directly (as modulated Region 1 currents) they cause ac variations in ionospheric Pedersen currents and Region 2 field-aligned currents at lower latitudes. These varying currents cause transverse distortions of magnetospheric field lines, and launch waves with frequency content matching those upstream.

In Figure 3b we show the "transistor action" at the ionospheric foot of the proposed wave entry path in more detail. Dayside Region 1 and Region 2 currents are coupled by ionospheric currents at cleft/cusp latitudes. Periodic precipitation of particles will modulate the ionization and conductivity of the cusp/cleft ionosphere, and thus modulate ionospheric and Region 1 — 2 current flow, in a manner analogous to the way in which a small, variable base current in a transistor modulates a much larger variable flow of current from collector to emitter. In both cases a small "base current" modulates the electrical properties of a region of relatively low conductivity connecting two regions of relatively high conductivity. In this manner magnetosheath turbulence will be transmitted inward to L shells in the dayside magnetosphere to the extent of the inner edge of the Region 2 current sheet, i.e., in a region covering most of the magnetosphere outside of the plasmapause.

C. Radial Boundaries of Pc 3-4 Pulsations in the Dayside Magnetosphere

As documented in a recently published paper by Takahashi and Anderson [1992], there is a significant gap typically near L ~ 4 where no transverse Pc 3 pulsations occur. This gap was first presented by George Ho, who is now a graduate student at the University of Maryland. Ho et al. [1991] interpreted this gap as evidence that the excitation of Pc 3 pulsations outside the gap was due to field aligned current excitation rather than the conventional excitation mechanism by mode coupling from compressional waves. In response to comments made when the Ho et al. [1991] paper was presented at the Spring 1991 AGU meeting, we have this past spring resumed efforts to model the radial profile of plasma densities in the dayside outer magnetosphere. In this we have been guided by the observed density profiles reported by Horwitz et al. [1986, 1990], who observed a multiple-plateau structure on the dayside, which during quiet times which could extend well beyond synchronous orbit. We have now modeled the resonant frequencies corresponding to such plateaus, using a simplified density distribution model, and find confirmation for our initial suggestion. We intend to present these new results at the Fall 1992 meeting of the AGU in San Francisco.

D. Source Regions for Correlated ULF-VLF Pulsations

We have just begun work correlating data from AMPTE CCE with simultaneous ground data from two Antarctic stations, South Pole (at cusp latitudes, L ~ 13) and Halley Bay (near L = 4). We have found excellent agreement in occurrence times between Pc 3 pulsations at all three stations when all are located on the dayside. As expected, when IMP 8 magnetometer IMF data are available, they show conditions favorable for the growth of upstream waves (low IMF cone angles) when the magnetospheric Pc 3 pulsations are observed. It has been observed for

several years that dayside high latitude VLF hiss and/or chorus is at times modulated at Pc 3 frequencies, but the mechanism(s) of this modulation are not understood. We have been collaborating with Keith Morrison of the British Antarctic Survey in this study, and expect to make a first report of our results at the spring 1993 AGU meeting.

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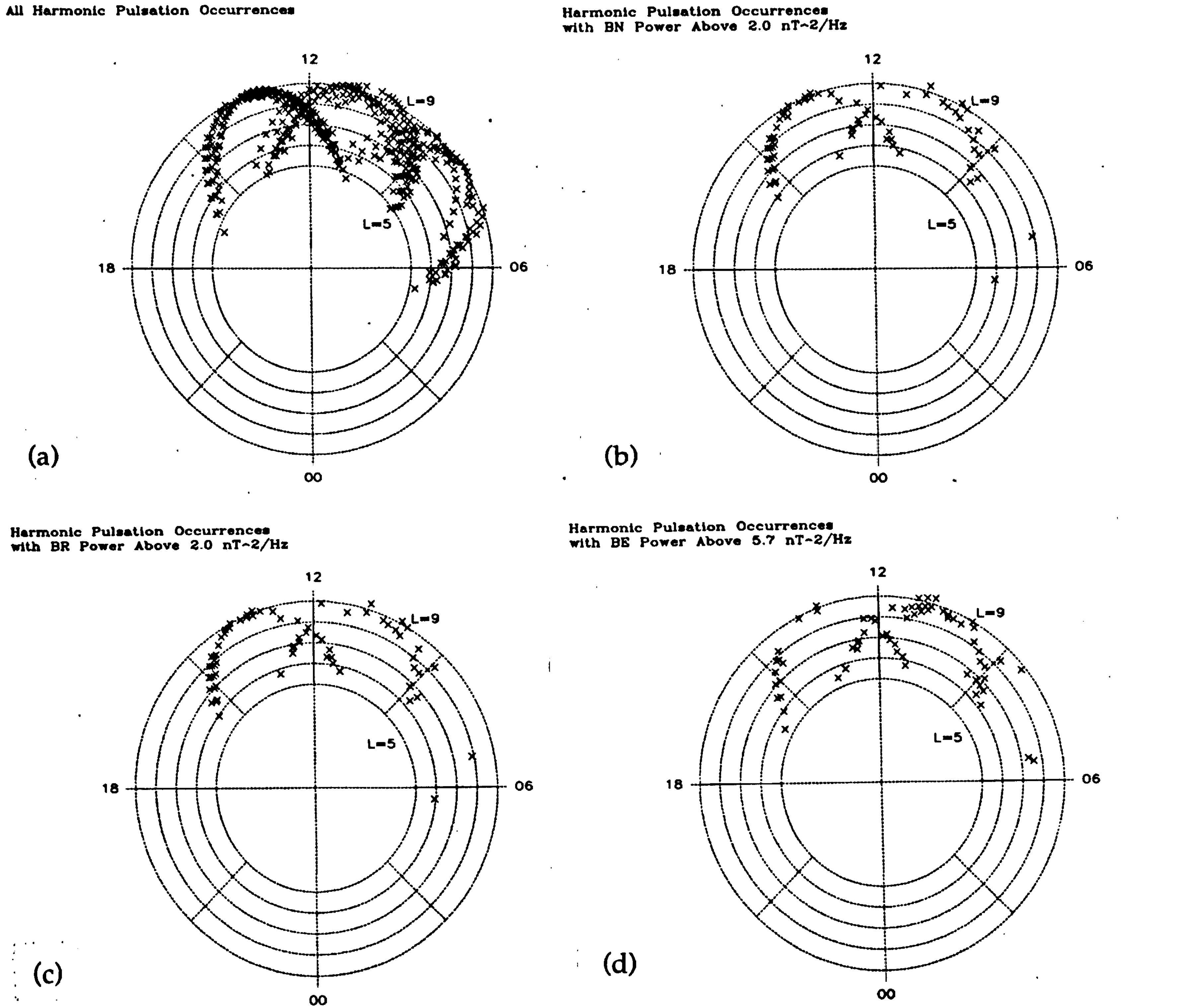
FIGURE CAPTIONS

Figure 1. Scatter diagrams of harmonic pulsation event occurrences as a function of local time and L shell. Panel (a) shows the distribution of all 459 harmonic events. The remaining panels show the distribution of events with power level higher than one standard deviation above the logarithmic mean for BN (b), BR (c), BE (d), BE/BN (e), and BR/BN (f). Panels (g) and (h) show the distribution of events with power level lower than one standard deviation below the logarithmic mean for BE/BN and BR/BN.

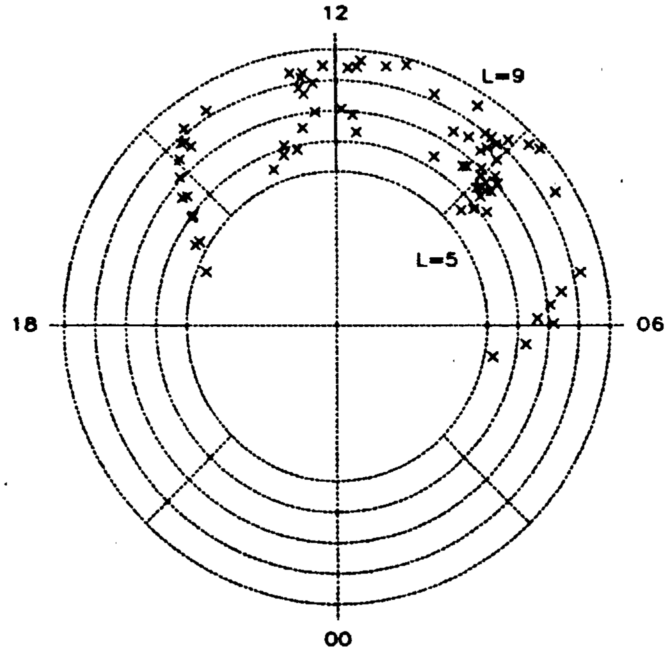
Figure 2. Scatter diagrams of more broadband pulsation event occurrences, as in Figure 1. Panel (a) shows the distribution of all 419 more broadband events. Panels (b) and (c) show the distribution of events with power level higher than one standard deviation above the logarithmic mean for the BN power and BE/BN power ratio.

Figure 3. A sketch of the proposed AC current model of entry of upstream wave signals. Left: Magnetosheath turbulence impinging on the magnetopause causes 1) modulated precipitation of otherwise trapped electrons, and/or 2) modulated flow of field-aligned currents (arrows) along boundary layer/cleft/cusp field lines. The view is from the dusk meridian Right: Ionospheric detail of the model. Modulated precipitation varies the conductivity of the ionosphere, which controls the amplitude of Pedersen currents and thus the connection between region 1 and region 2 Birkeland currents. These region 2 currents drive the Pc 3-4 pulsations.



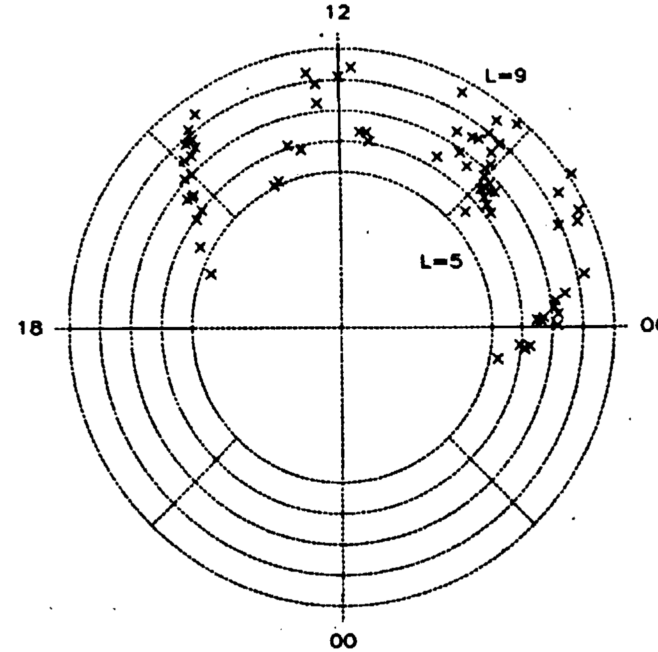
All Harmonic Pulsation Occurrences
12
18
06
00
L=9
L=5
(a)
Harmonic Pulsation Occurrences
with BN Power Above 2.0 nT^2/Hz
12
18
06
00
L=9
L=5
(b)
Harmonic Pulsation Occurrences
with BR Power Above 2.0 nT^2/Hz
12
18
06
00
L=9
L=5
(c)
Harmonic Pulsation Occurrences
with BE Power Above 5.7 nT^2/Hz
12
18
06
00
L=9
L=5
(d)

Harmonic Pulsation Occurrences
with BE/BN Power Ratio Above 5.7



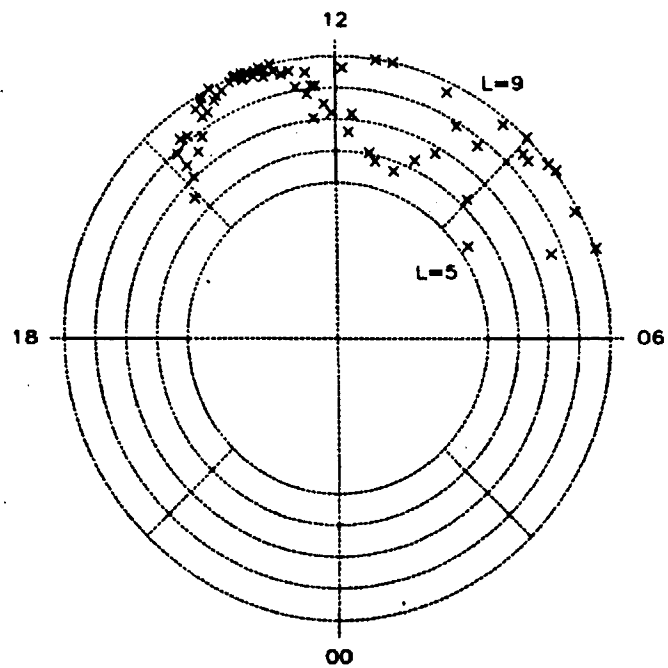
(e)

Harmonic Pulsation Occurrences
with BR/BN Power Ratio Above 1.9



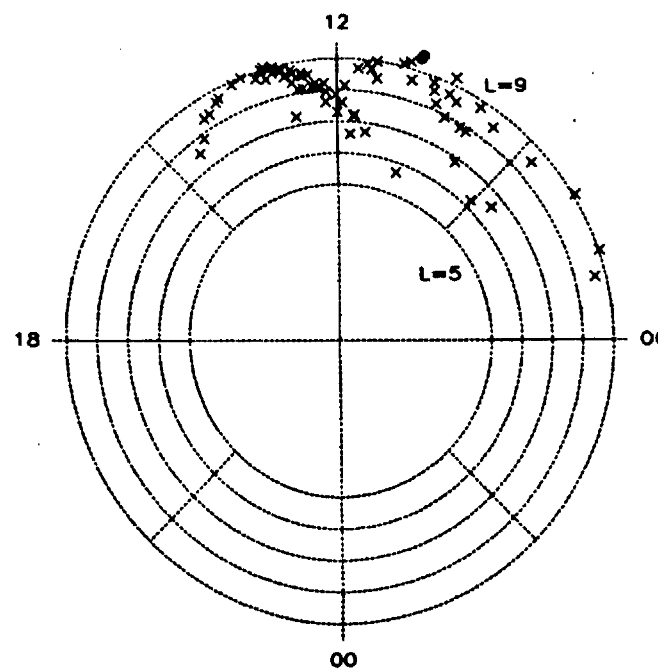
(f)

Harmonic Pulsation Occurrences
with BE/BN Power Ratio Below 1.3



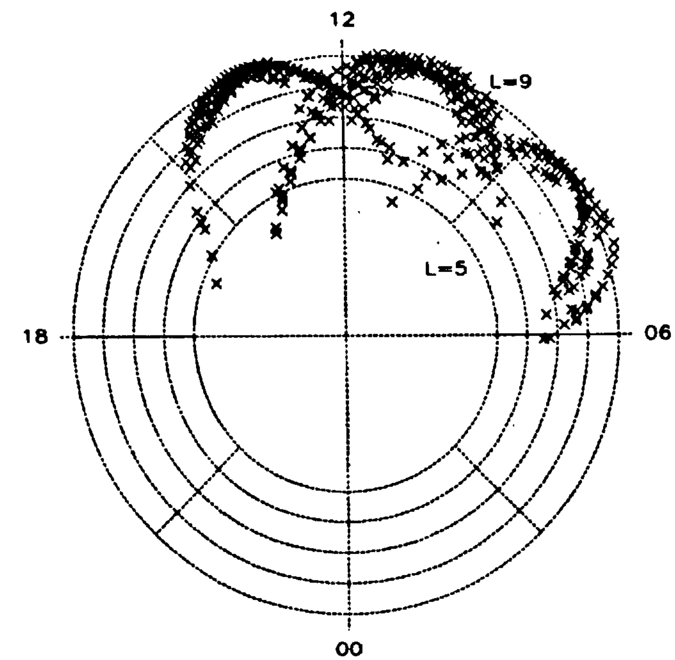
(g)

Harmonic Pulsation Occurrences
with BR/BN Power Ratio Below 0.5



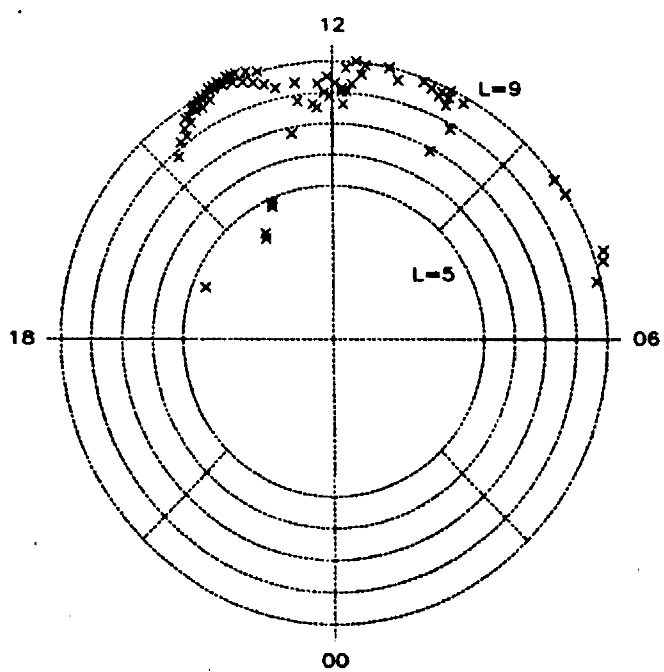
(h)

All Broadband Pulsation Occurrences



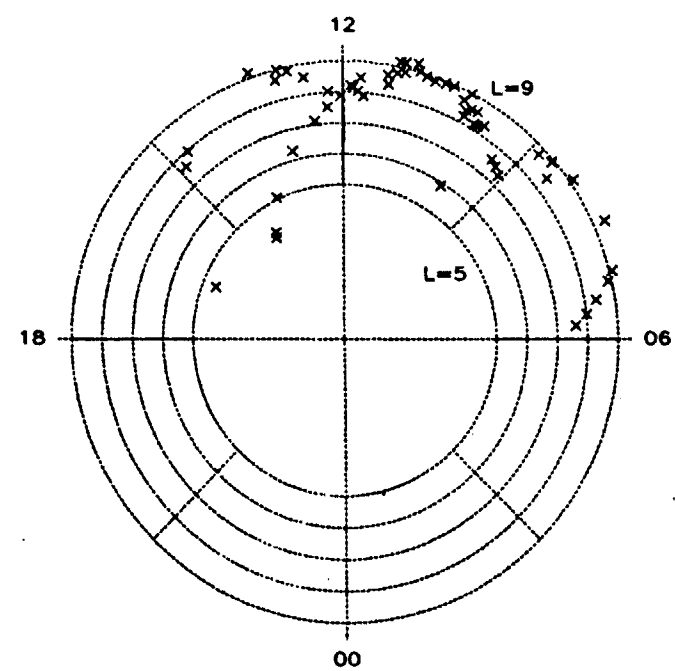
(a)

Broadband Pulsation Occurrences
with BN Power Above 3.0 nT-2/Hz

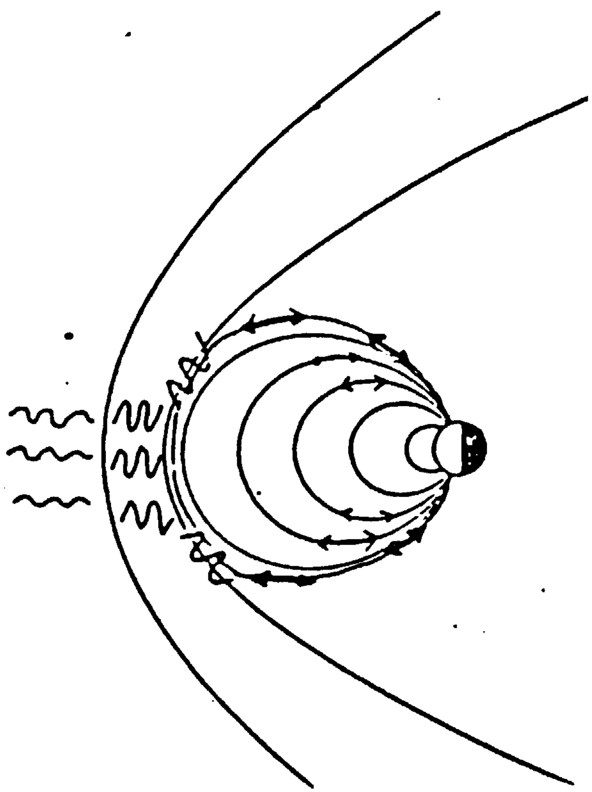


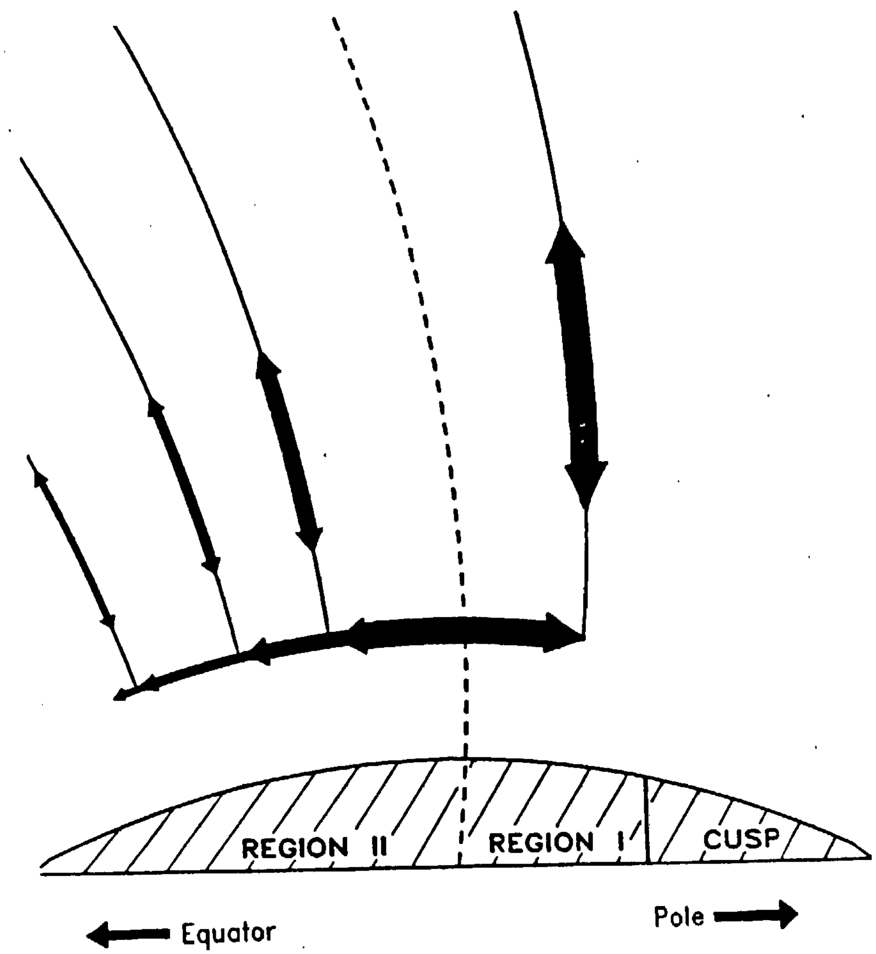
(b)

Broadband Pulsation Occurrences
with BE/BN Power Ratio Above 3.4



(c)





REGION II
REGION I
CUSP
Equator
Pole